

## **Numerical simulation of a permittivity probe for measuring the electric properties of planetary regolith**

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Measurements of dielectric regolith properties are particularly useful for the detection of subsurface water/ice deposits in various forms, providing important constraints on the volatile content of planetary sub-surfaces and interiors. Additionally, near-surface environmental processes like impact gardening, space weathering, material erosion, vertical mixing, lateral redistribution, and volatile exchange can be addressed more carefully if combined with measurements related to soil stratigraphy and texture. We present a numerical simulation technique that parallels the development of an in-situ probe for measuring electric key properties such as conductivity and permittivity of planetary, asteroid, and cometary regoliths. Our simulation techniques aim at accompanying the hardware development and conduct virtual experiments, e.g., to assess the response of arbitrary heterogeneous conductivity and permittivity distributions or to scrutinize possibilities for spatial reconstruction methods using inverse schemes. In a first step, we have developed a finite element simulation code on the basis of unstructured, adaptive triangular grids for arbitrary two-dimensional axisymmetric distributions of conductivity and permittivity. The code is able to take into account the spatial geometry of the probe and allows for possible inductive effects. In previous studies, the non-inductive approach has been used to convert potential and phase data into apparent material properties. By our simulations, we have shown that this approach is valid for the frequency range from  $10^2$  to  $10^7$  Hz and electric conductivities of  $10^{-8}$  S/m typical for planetary regolith. We prove the accuracy of our code to be better than 10% using mixed types of boundary conditions and present a simulated vertical log through a horizontally stratified subsurface layer as a representative example of a

heterogeneous distribution of electrical regolith properties. Resolution studies for the given electrode separation reveal that the material parameters of layers below several centimeters thickness cannot be retrieved if only the apparent quantities are considered. Therefore, spatial distributions of the complex sensitivity are presented having in mind a future data inversion concept that will permit describing the impact of a heterogeneous environment on the apparent quantities. Finally, as an example of the broad range of possible virtual experiments, a practical issue is discussed concerning data bias produced by a vacuum gap between the probe and penetrated regolith. In a homogeneous case, the probe performs a robust determination of the electric material parameters if the gap is less than a few millimeters.